CYBERTRAN: A SYSTEMS ANALYSIS SOLUTION TO THE HIGH COST AND LOW PASSENGER APPEAL OF CONVENTIONAL RAIL TRANSPORTATION SYSTEMS

Dr. John A. Dearien, Richard D. Struthers, Kent D. McCarthy
CyberTran International, Inc
2300 N. Yellowstone
Idaho Falls, Idaho 83404
http://www.cybertran.com
email - chuchu@srv.net

Introduction

The CyberTran (**Cyber**netic **Tran**sportation) is a system that was designed from the ground up to address two of the primary problems associated with public transit - high costs and low passenger appeal. The "high costs" part of the problem includes both capital and operating costs. The "low passenger appeal" aspect of the problem includes both environment and operating considerations. This paper will first describe the CyberTran system, and then describe the systems analysis process relative to capital costs that led to the particular vehicle size and system configuration. Following this will be a discussion on the particular aspects of this "small vehicle" system that should make it more appealing to the traveling public than conventional technologies. CyberTran was designed, built, and tested at the Idaho National Engineering Laboratory, a United States Department of Energy Research, Development, and Engineering laboratory in southeastern Idaho.

CyberTran Test Vehicle #2 on Transporter

System Description

CyberTran is a passenger and light cargo transportation system utilizing large numbers of small (6 - 20 passengers), light weight (10,000 lb. loaded), electrically powered, computer controlled (no driver), steel wheel-on-steel-rail vehicles operating in an elevated guideway at speed ranges from tourist (20 - 40 mph), to urban (40 - 75 mph), to high speed (75 - 150 mph).

Vehicles Test Vehicle #2, on its transporter (which is a modified arch truss guideway section) is shown in the adjacent photo. The vehicles are 38 feet long, 6 feet wide, 6 feet high, with a 7500 lb. empty weight. The vehicles have a standard 20 foot by 6 foot passenger area with 4 doors on each side. This geometry allows seating configurations from 6 to 20 passengers, depending on size and orientation of the seats. Thus, a standard, mass produced body shell can be used in a variety of applications and traffic flows.

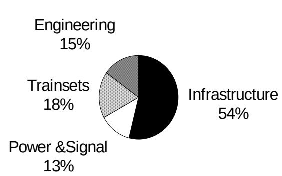
Guideway The light weight (~10,000 lb.) of the operational vehicles permits a very light weight section to be used in the elevated guideway. This light weight guideway is not only economical to produce in a mass production mode, but a semi-automated erection process reduces construction costs. Weight saving from these light weight components carry through the columns and into the footings. Guideway sections can be lightweight steel trusses or heavier prestressed concrete channels.

Stations Loading/unloading of the vehicles is off-line in order to maximize system efficiency and minimize travel time for the on-board passenger. The combination of off-line loading and large numbers of vehicles allows the system to approach "direct-to-destination" operation over much of the operating spectra. Stations can range from a simple track-side concrete pad to elaborate interchange facilities, and, since the vehicles and their trackage are so compact, stations can be easily placed within existing buildings.

Control CyberTran utilizes a Communication Based Control system, with high speed redundant computers in the vehicle providing the primary control and redundant central computers monitoring the system and ready to assume control if required. Monitoring and control of the vehicles, both by the central computers and the individual vehicle computers, is based on feedback between vehicles and the guideway (sensors) at 300 foot intervals along the guideway. Identity, position, speed, and operational status of each vehicle is updated and transmitted to the central computers and other vehicles at each guideway sensor location.

Power and Propulsion Propulsion is provided by two 100 HP electric motors, each propelling a single solid axle at each end of the vehicle and providing the vehicle with all wheel drive. Testing to date has utilized DC motors, but production vehicles will utilize AC motors. Evaluation of a linear synchronous motor (LSM) and control process developed at MIT is underway and could be utilized in the future, but the technology will require testing and cost evaluation before consideration for CyberTran. The LSM has the potential to solve many problems now being faced by electric powered steel wheel on steel rail vehicles, such as traction, electrical shock, and power transmission to the vehicle. The vehicle has been designed to be easily modified to utilize different motors and control units, and variations are expected to be evaluated during the testing program.

Figure 1 System Costs



Minimization of Cost Factors

The capital cost of typical rail systems is concentrated in the expense of the permanent way.[1] Figure 1 shows a typical distribution of costs over the primary components of the system. It is evident from these costs that if capital costs are to be reduced, something must be done to reduce the permanent way costs.

The most direct driver of permanent way cost is the weight of the vehicles traveling over the rails. It is this individual vehicle weight that controls the size of the rails, strength of the roadbed, size of bridge girders, and for electrical vehicles, the size of the power components needed to power the system.

Figure 2 shows that vehicle weight goes up with capacity, as expected, and does so in a rather linear fashion.[2]

Figure 2 Vehicle Weight vs Capacity

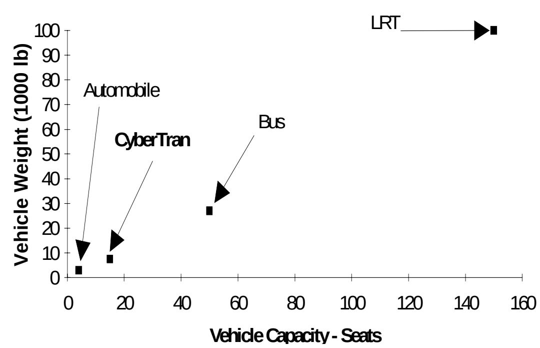


Figure 3 illustrates, however, the non-linear relationship between vehicle weight and permanent way size and associated cost. Large structures add their dead weight to the load to be carried and the larger components require progressively more construction time and cost.

The remaining factor in this sub-system relationship is the optimum size of the vehicle to minimize system cost. Figure 4 shows the relationship between vehicle capacity (thus weight) and the capital cost per seat for a range of common transportation modes.[3]

The relationship between capacity and cost per seat is a "bathtub" type curve with large high technology systems like the French TGV being rather expensive and the price per seat coming down as the size and complexity

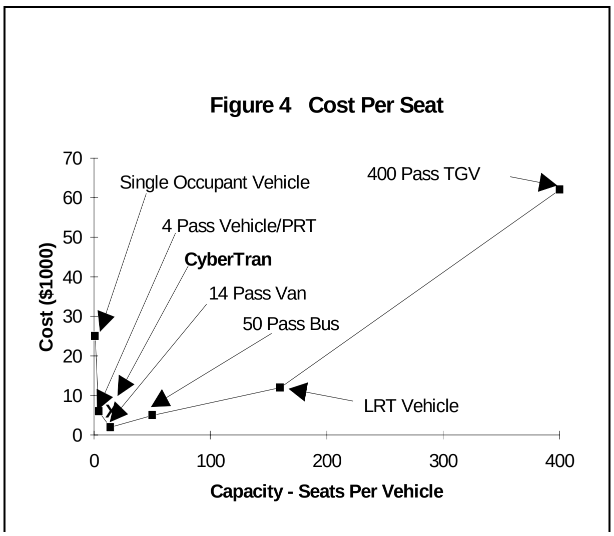


Figure 4 Cost Per Seat

of the vehicle decreases.
As the size of the vehicle decreases, however, at some point the number and total vehicle costs begin to rise rapidly. As the effective seating capacity approaches unity, the system starts to look similar to a taxi operation, with very high operating costs and fares required at that point. Given that a certain amount of equipment is required to propel, control, and environmentally condition a vehicle, there is a limit to how small a vehicle can be made and still carry a person. One sees, however, that the drop in vehicle numbers with increasing vehicle size is also quite rapid, very quickly getting into the passenger range covered by systems like Raytheon's PRT 2000[4] and then into the larger passenger range of CyberTran. The relationship between numbers of vehicles required to carry a particular load and the seating capacity of each vehicle is shown in Figure 5. This figure shows that the gains realized by making vehicles larger, thus cutting down on certain "per vehicle" costs, are dramatic at first but diminish in relative effect as the vehicles get larger. Combining the permanent way sub-system cost

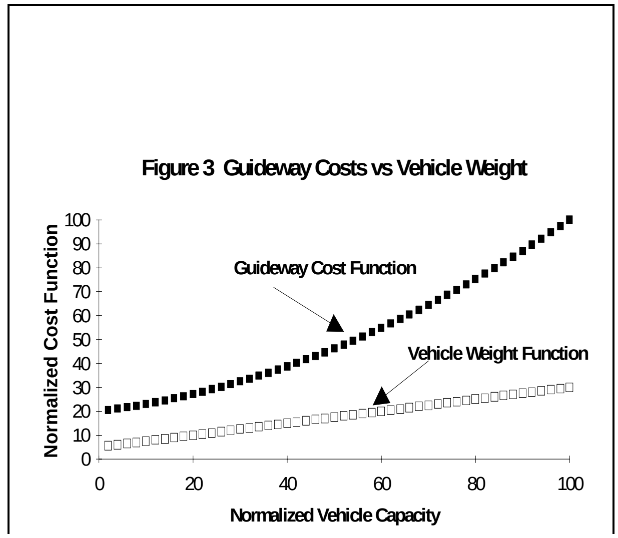


Figure 3 Guideway Costs vs Vehicle Weight

relationship (Figure 3) with the vehicle capacity - cost relationship (Figure 4), and the individual vehicle cost function (Figure 5), one obtains the combined system cost relationship of Figure 6.

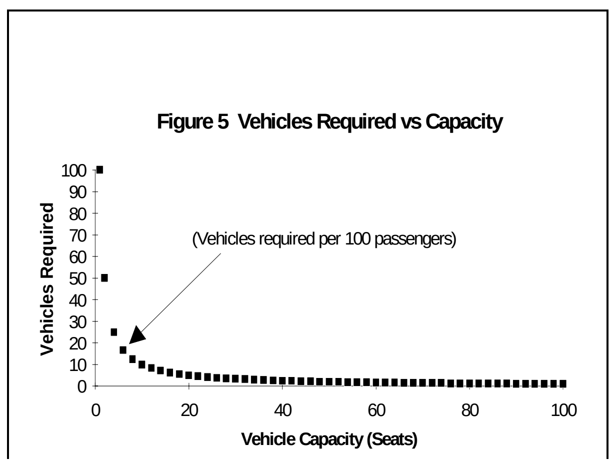


Figure 5 Vehicles Required vs Capacity

Figure 6 indicates that smaller vehicles, and thus lighter and with lower passenger capacity, reduce the cost of the system, but this process can only be taken so far. The optimum location (read vehicle size and capacity) in this minimum area of the system cost curve is dependent on the system operating conditions. The optimum size of a lower speed system like PRT 2000 was selected as 4 seats, while the higher speed and longer distance CyberTran system was configured for 6 to 20 seats.

Component Costs

CyberTran was designed to minimize total cost by taking a systems analysis approach to the components which make up the system, minimizing the capital cost, construction cost, and the operating cost of each component.

Vehicle The vehicles were designed to be mass produced from readily available materials using conventional metal working technology. The vehicle design, with its multiple doors, can be configured to fit a number of applications depending on the seating type and arrangement. The vehicle is constructed of thin wall stainless steel sections for low cost, high strength, and low maintenance. Non-structural components such as glazing, doors, and internal panels, are designed for easy removal and replacement if needed.

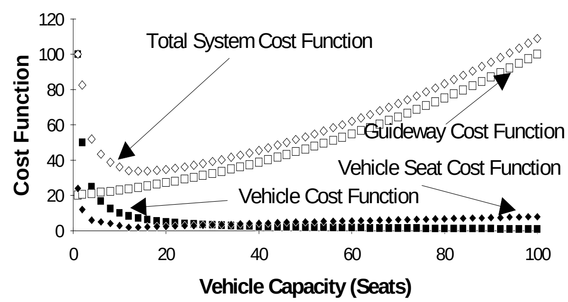
Guideway The guideway was designed as a standard 50 foot unit to support one lane of flow. By keeping each guideway section to one lane, there is no asymmetric torsional load on the section and the section can be optimized to carry a single vehicle. The standard, straight sections have enough side clearance to lay a curved track section through the span. Mass production of a standard guideway section in a steel fabrication plant or a prestressed yard minimizes the costs.

Column and footing sizes are minimized due to the low combined weight of the truss, base pad, and vehicle being approximately 40,000 lb. With a 3 foot by 10 foot concrete footing setting on a 5 foot by 12 foot bed of standard railroad ballast, the bearing load on the soil is only 660 psf. The concrete footing is locked into the ballast bed in order to provide the same type of lateral stability obtained in a conventional railroad tie and ballast bed.

The guideway components are designed to be erected "off the end" of the completed section with an erection fixture. This allows the system to be erected without significant ground preparation or rerouting of utilities, a large cost component in most conventional transit systems.

Power Distribution Use of smaller vehicles can have a significant effect on electrical component size and costs. A French TGV can require up to 9 mw and when two trains pass at maximum power, a local requirement of 18 mw is realized. CyberTran is projected to require between 100 and 120 kW per vehicle at top speed, or up to 240 kw at the point where vehicles pass. This factor of 75 between local power requirements of the two systems results in significant decreases in sub-systems such as transformers, power control units, and conductors. The per passenger electrical need of CyberTran is approximately half that of a TGV (10 kw/pass for CyberTran vs. 22 kw/pass for the TGV)[5] due to the smaller vehicle size and lower vehicle weight per passenger (500 lb/pass for CyberTran vs 2500 lb/pass for the TGV- locomotives included). While there is some saving in power requirements due to vehicle size, the major effect in capital cost is obtained from distributing the power requirements over a long section of track.

Figure 6 System Cost vs Vehicle Capacity



System Effects of A High Capital Cost Permanent Way

In the sale of transportation services, much like the sale of any commodity, the prime factors in obtaining an acceptable return on one's investment are (1) the initial cost of the commodity and (2) the cost of selling that commodity to a buyer. In the case of transit systems, the commodity for sale is a seat. The "cost" of that seat is the capital investment necessary to put it in service, and the higher the cost, the more one has to obtain for its sale and/or the more often one has to sell it. Thus, if one can produce a seat which provides the same, or better, service than other transit seats and at a much smaller capital cost, one can realize a higher rate of return on one's investment. In many cases, this return on investment can be in the form of profit, as opposed to nearly all forms of rail transit today, which lose money.

Table 1 shows some basic data of transit systems that have been developed and are proposed.[2,5] The permanent way (PW) costs are all capital costs less vehicle costs. The reader can see from Table 1 that the system cost per seat will decrease as addition seats are added to the system. Figure 7 shows this effect, but it also shows that there is a practical limit to how many seats can be added to and utilized by the system, thus limiting the minimum cost of an available seat.

Table 1 Capital Cost Parameters of Representative Transit Systems

System	MAX	NEC	FOX	H'way	CyberTran	PRT
PW $	$265M	$1.3B	$4.2B	$20M	$4M	$17M
Miles	15.1	230	320	1	1	1
$/Veh	$2 M	$25M	$25M	$10K	$100K	$25K
S/Veh	166	345	400	1	15/20	4
#Veh	26	26	26	200	2/16	50
$/seat	$13K	$72K	$62K	$10K	$7/5	$6K
Initial System	$73K	$217K	$466K	$110K	$140K	

$87K
$/seat $15K

Figure 7 shows the range of practical application of

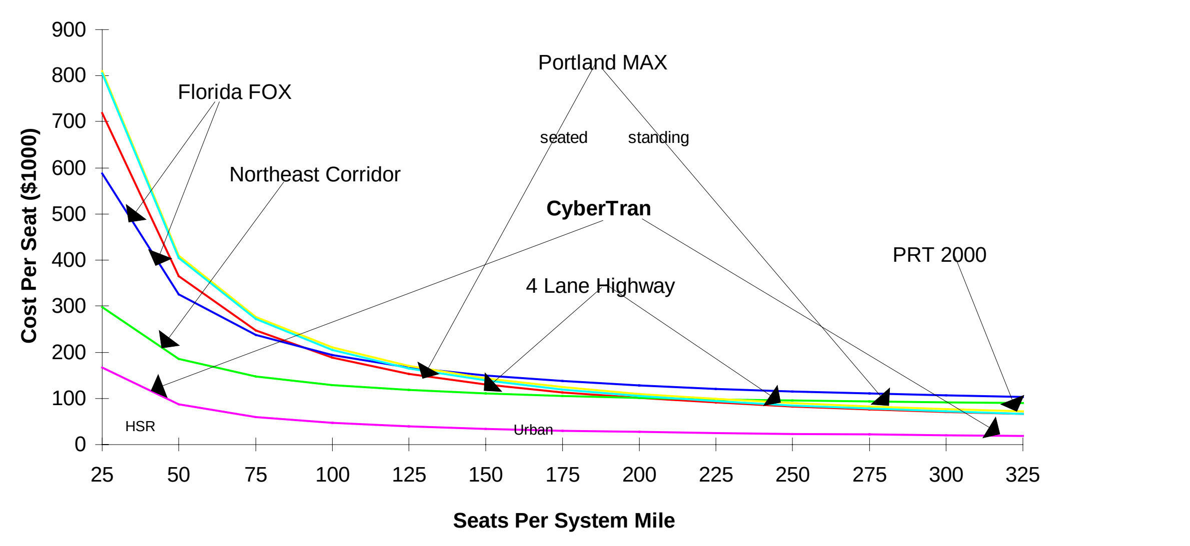


Figure 7 Capital Cost Per Seat

various systems with single vehicle consists. The numbers assume a "system mile" has bi-directional traffic with vehicles on both lanes. The Florida FOX system is shown at its projected seat density (32 seats/system mile) and at a density comparable to the Northeast Corridor (NEC - 45 seats/system mile). Portland MAX is shown for the range of seats (76 s/v) and total capacity (166 pass/v). CyberTran's range considers two 15 passenger vehicles per system mile (30 seats/system mile) in the high speed rail mode and sixteen 20 passenger vehicles per system mile (320 seats/system mile) in the urban LRT type mode. PRT 2000 is assumed at 80 vehicles per system mile (320 seats/system mile).

The "Highway" was placed in the table (at $20,000,000 per mile) to show that it can be compared with other transportation systems regarding capital costs and "cost per seat". Since a smooth flowing 4 lane highway contains approximately 150 to 250 vehicles per mile (1.5 - 1.0 second headway, generally with 1 person per vehicle - average 200 seats per mile), a similar comparison of cost per seat can be made even for highways.

CyberTran has two values, with the $140,000 per seat being for the high speed version and the $15,000 per seat being for the urban, LRT class operation.
The practical limits on the available seats for the various systems are generally set by the headway between vehicles or the minimum time required to load/unload a particular unit. For example, if one takes the 26 train-sets destined for the NEC and distributes them evenly along both directions of the 230 miles from New York to Boston, one has a train every 17.7 miles, or 40 seats per system mile. The expected travel time of 3 hours between New York and Boston results in an average speed of 76 MPH. This results in a headway between trains of 14 minutes, which is about the minimum time required to go through a unload-load-dispatch cycle. Thus, the minimum cost per system seat for the NEC is going to be about $217,000 for trains run as single units, or about 3 times the unit per seat cost of $72,500. The NEC, however, benefits greatly from the fact that the cost of the permanent way is only an upgrade cost of $1.3 billion, or about $5.7 million/mile. One sees a very different picture if the permanent way must be built from scratch, as in Florida.

Florida FOX is starting off with a $4.2 billion infrastructure cost ($13 M/mile) and 26 train-sets at a price of approximately $25 million each, resulting in a system average cost of $466,000 per seat. If one assumes the average speed of the NEC (150 MPH with stops) of 76 MPH, the trains are spaced every 25 miles (32 seats per system mile) with a headway of 19.5 minutes. If one goes to the headway of the NEC (14 minutes), Florida FOX can add 10 more train-sets, resulting in a seat density of 45 seats per system mile and a system average cost of $351,000 per available seat. These numbers show the tremendous impact of a high up-front capital cost on the price of a transit system's primary salable asset - an available seat. One can see from the trend of the curve in Figure 7 that it is necessary to place a significant number of trains on the rails (and have the traffic to support them), before the per unit seat cost drops down to the range of highway costs.

The numbers and discussion above show the need to get the capital costs of the fixed infrastructure down if one is going to decrease the per seat cost of a rail transport system. The numbers in Table 1 show that the projected cost for CyberTran reduces this per seat cost down to less than a third of the cost of a high speed rail system of comparable or lesser capacity. The NEC offers a potential of 1412 seats per hour (per direction) with its average speed of 76 MPH and its directional seat density of 20 seats per mile. CyberTran can supply a throughput of over 2000 seats per hour per direction with 15 seats per mile and an average, non-stop speed of 135 MPH.

There are similar comparisons between CyberTran and LRT systems for speeds in the 60 MPH range (which includes highways). The capital costs of the Portland MAX system raised the system seat average cost to $73,500 per seat, nearly 6 times the unit per seat cost of $13,000. A similar ratio is realized in CyberTran where the per seat cost of $5000 is elevated by a factor of 3 to a system average seat cost of $15,000 for a similar seat density per mile, but the final system average seat cost is approximately 1/4 of the conventional LRT system and less than 1/4 of the equivalent highway cost per space.

CyberTran is designed to compete with High Speed Rail in its high speed, one vehicle per mile operating mode and compete with LRT's in the slower speed, four vehicle to the mile mode. With higher average system speeds due to direct to destination routing, CyberTran can be operated pphpd with single vehicle consists at a passenger throughput equal to LRTs.

Reality Check on System Metrics The CyberTran system is a significant, paradigm shift in the cost and operation of rail transportation. A natural question arises as to the realism of being able to construct and operate components at the weight and cost proposed in this system. Table 2 compares critical parameters between a number of familiar transportation systems and CyberTran.

Table 2 Critical Parameters in Transportation Systems

System	HSR	LRT	Bus	Buick	CyberTran
Wt/Pass	980 lb*	600 lb	500 lb	500 lb	500 lb
$/Seat	$62K	$13K	$5K	$4K	$7K
$/Lb	$25	$22	$9	$8	$14

*does not include locomotives or dining car[5]

The lighter weight CyberTran ends up looking a little more like an automobile or bus in the weight per passenger category, which could be expected when one can do away with the heavy wheel set and under-frame associated with rail vehicles, but is in the range of the state of the art of metal frame construction. Locomotive propelled systems are quite heavy, on a per seat basis, because of the penalty paid for the locomotive (or the two locomotives in the case of TGV).

Cost per seat and cost per pound for CyberTran is between that of typical road vehicles and typical rail vehicles, reflecting the light weight steel construction and mass production effects of road vehicles as well as some of the heavier and expensive components of rail vehicles.
All of the above comparisons were made using single vehicle consists, either one TGV, one LRT, or one CyberTran. The system average seat costs of each system will be lowered if multiple vehicle consists are utilized, but the disparity in system average seat costs will still remain between conventional rail systems and CyberTran. This can easily be seen in the curves of Figure 7 as the seats-per-mile are increased for each system.

Passenger Appeal of Smaller Vehicles

While the primary reason for designing a passenger transit system based on small vehicles was to decrease the capital cost of the system, advantage was taken where possible of the operational possibilities which the small vehicles and the computer control aspect of the system offered.

On Demand Service A CyberTran system could have several hundred vehicles in operation and these vehicles would be stored in and around stations, ready for use. Thus, a vehicle would always be available when needed. In low traffic hours, it might be expedient to delay the departure of a vehicle for a few minutes to potentially add other passengers, but after a set period of time the vehicle would leave. In busier periods, the small vehicles would be expected to fill up as fast as they could be brought up to the loading dock.

Direct To Destination Routing Stations operate with off-line loading and unloading. This means that in-transit vehicles do not have to stop at intermediate stations and thus realize a higher average travel speed and a lower travel time to their destination. The average system speed of the Portland MAX is approximately 16[2] MPH. Computer simulations of a CyberTran system operating over a route structure similar to Portland's indicate an average velocity of 49 MPH, over three times as fast in getting to a passenger's destination.

24 Hour Service With the system under computer control and all of the facilities monitored in the control center, a CyberTran system can be operated around the clock. A full 3 shift operation is planned for the control center. Track maintenance would be done on a scheduled basis during low traffic periods and with traffic bypass.

Off Line Loading/Unloading This operational process has a positive effect on both passengers and operating economics. To the passenger, it offers not only the advantage of faster travel to one's destination (discussed above), but it offers more time for loading and unloading while in the station. Conventional LRT and Metro systems operate, generally, with approximately 30 second station stops. Off-line loading and unloading does not require such a rapid pace process to maintain a system schedule and passenger throughput.

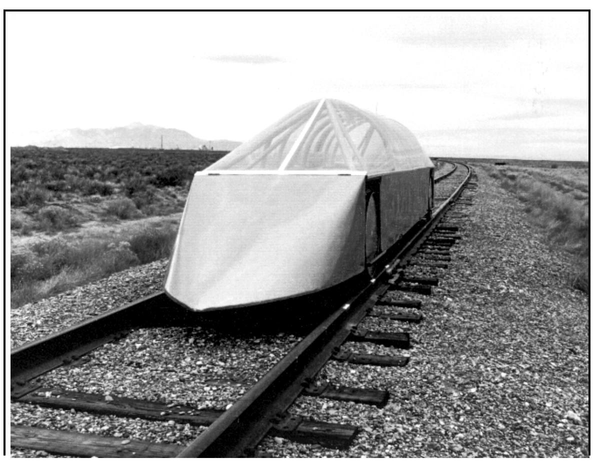
Security Security is defined as the protection of passengers from injury by other passengers, whereas safety is protection from injury by the system.

The small vehicles, and the large numbers which would be used in most systems, means that there are frequent departures to all destinations. If a person does not want to ride with a particular person or group, it will be only a short time before another vehicle is departing for that destination. In addition, the vehicles are effectively divided into four separate compartments, each accessible only by two doors from the outside. Once under way, passengers are not free to roam up and down the length of the vehicle and bother other passengers.

The direct to destination aspect of operation also precludes an unwanted passenger from getting on a particular vehicle while it is in transit to its destination, providing peace of mind to passengers traveling during off hours through questionable security areas. Communication is provided between each vehicle and central control. At the slightest hint of danger or an emergency, a passenger can request the intervention of central control. An additional option available is a button, similar to the cord on old trolley systems, that, when pushed, will route the vehicle immediately and direct to the authorities.

<u>Safety</u> CyberTran has a number of safety systems both built in and inherent to the overall system. Control and communication systems are redundant and are similar to systems now in use in conventional rail systems.

Each line of traffic is contained within a separate guideway and head on collisions are impossible. Collisions by overtaking of vehicles are prevented by very frequent (once per second) monitoring of all vehicle positions and maintaining safe separation distances between vehicles.



Test Vehicle #1 During Test Series at INEL

Emergency power sources are maintained so that communication, control, and environmental conditions can be maintained in the vehicles while they are slowly brought back to the closest station. Vehicles are capable of pushing each other in the case of individual vehicle failure.

Passenger egress from the vehicles is possible and pathways along the guideways are available, leading to points where passengers can descend from the elevated guideway.

A "slow" air bag, developed at the Idaho National Engineering Laboratory for restraint of criminals in police custody[6], will be used for emergency deployment in the event of an impending collision. This device, in conjunction with seat belts, should make CyberTran vehicles much safer than conventional rail vehicles.

<u>Access and Seating</u> Access to the CyberTran vehicle is through 4 doors on each side, which allows 1 - 2 step access to every seat in the vehicle. Vehicles are a low floor design and ADA accessible. CyberTran is designed for all of the passengers to be seated. A traveler will not, therefore, be confronted with the option during rush periods of either standing or having someone stand over and around them. The layout of the vehicle, with 4 doors on each side of the vehicle, permits a pitch of 48 inches between seats (similar to First Class in aircraft) as a standard on all vehicles, allowing ample leg room and sufficient room for baggage, strollers, etc.

<u>Visibility</u> The upper half of the CyberTran vehicles are glazed, much like the Vista Liner Observation cars of the Canadian Pacific Railroad, and offer a spectacular view of the outside. The view and closeness to the outside gives a feeling of volume and space not expected in a small vehicle the size of CyberTran.

Status of the CyberTran Program

Two test series have been completed at the Idaho National Engineering Laboratory. The first, carried out on 10,000 feet of specially constructed track, tested the basic mechanical aspects of the system and was run to a top speed of 55 MPH under computer control.

The second test series was conducted to test the self steering capability of the full radial, single axle propulsion trucks. The second tests (see adjacent photo) were run on conventional rail at the Idaho National Engineering Laboratory and proved the capability of the single axle trucks to steer along tangent and curve track without locking up the flanges during curving or transition between tangent and curve. Two test vehicles have been constructed. The first vehicle was used in the field tests and the second was built for ergonomic and mechanical component engineering. Engineering test sections have been constructed for the elevated guideway, column, and footing components. Various rail sections have been tested for material wear and adhesion factors.

Computer simulation of the CyberTran vehicle was performed at the AAR Transportation Technology Center in Pueblo, Colorado using the NUCARS code. The vehicle was computer simulated and found to be stable at speeds up to 160 MPH.

The CyberTran technology has been spun out of the Department of Energy laboratory system and is now being commercialized by CyberTran International, Inc. Research continues on basic components of the system while funding is being sought for a test track which can be used to bring the system to commercial competitiveness.

Summary

A systems evaluation of rail transportation components, performed with respect to minimization of total system cost, indicates that a system based on small vehicles should be pursued, due to the favorable effects of small vehicle weight and power needs on infrastructure costs. Smaller vehicles are shown to not only decrease the capital cost of the system, but produce an operating system which can be more appealing to the riding public than conventional, large rail components.

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